

## Root damage affects nitrogen uptake and growth of young Fuji/M.26 apple trees

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### SUMMARY

Effects of root damage during the transplant process on growth and nitrogen (N) uptake were studied with one-year-old bench-grafted *Malus domestica* Borkh 'Fuji' on M.26 rootstock apple nursery plants. Plants were potted after grafting and grown outside for one season. At the end of the season uniform trees were selected and randomly divided into four groups. One group of plants were moved into a 2°C cold room with soil and container intact (IR Treatment). Plants in other groups were removed from pots and stored as bareroot in the same cold room for three months. In the spring, bareroot plants were either: (1) transplanted with about 10% of the root system damaged during transplant (TP Treatment and Control-CK); or (2) root pruned by 25% (by volume) prior to transplant (RP treatment). Five trees from each treatment received 1 g of <sup>15</sup>NH<sub>4</sub><sup>15</sup>NO<sub>3</sub> at 12, 41 and 76 d after repotting. Control (CK) trees received no N. Trees were harvested 10 d after each N application, and plant growth and total N and <sup>15</sup>N content of different tissues were determined. Root pruning reduced plant total biomass and root biomass at the first two harvests, but the plants from the RP treatment had highest total plant biomass and root biomass at the third harvest. There was no significant difference in the new stem and leaf growth among IR, RP and CK treatments at harvests but the TP treatment reduced new shoot biomass. Plants with intact roots (IR) had the higher total N content while control plants (CK) had the lowest. Root pruning reduced <sup>15</sup>N uptake rate at the first two harvests but promoted it at the third harvest. Our results suggest that plant growth and nutrient uptake was suppressed by root pruning/damage during transplanting only in the early season, and the negative effects on growth and N uptake were offset later in the season by compensative root regeneration.

The root system performs several key functions for plants including: support for the above ground portion, water and nutrient uptake from the soil, and assimilation of some elements essential for plant growth (Faust, 1989; Fallahi, 1996; Rom, 1996). Roots also synthesize certain hormones that regulate plant growth and development (Shu *et al.*, 1993). Damage to the root system may affect root function and growth of the whole plant. However, proper root pruning (controlled root damage) has been a widely used tool to improve nursery stock quality and subsequent growth performance in horticultural practices (Geilser and Ferree, 1984a; Hipps *et al.*, 1996; 1999).

There is little nitrogen uptake until three weeks after bud break in young bare-rooted apple trees when established in the spring (Cheng and Fuchigami, 1997). In early spring, nutrient uptake is low as a result of low soil temperature and relatively inactive tree growth and function (Dong *et al.*, 2001; Hogue and Neilsen, 1986; Tagliavini *et al.*, 1991; Toseli *et al.*, 1999). Soil temperature and tree activity may only partially explain this delay of nutrient uptake in the spring. In newly transplanted bare rooted trees, the root system experiences some damage during the harvesting, storage and transplanting operations, which may also play some role in delaying nutrient

uptake. Bare root harvesting and cold storage of deciduous nursery stocks are commonly practised by deciduous nurserymen. Transplanting is a common operation in many horticultural practices (Geilser and Ferree, 1984a). Root damage during bare root harvesting, storage and transplanting may reduce nutrient uptake and suppress subsequent growth during plant establishment. The objective of this study was to evaluate the effect of different levels of root damage at planting on nitrogen uptake and growth of young apple nursery trees.

### MATERIALS AND METHODS

Bench-grafted Fuji/M.26 apple trees were planted in 4 l plastic pots containing a 1:1:1 (by volume) mix of peat moss, perlite and loam soil at Oregon State University in Corvallis, Oregon, USA. The trees were grown under outdoor conditions during 1998. Each tree was trained into a single shoot and fertigated with 10 mM nitrogen in a 20-10-20 (N:P:K) formula once every two weeks from May to August. At the end of the season, uniform trees were selected based on height and stem diameter for experimental treatments.

The selected trees were randomly divided into four groups with 20 trees in each group. After natural defoliation in late December one group of the trees was moved into a 2°C cold room with soil and pots intact (intact root, IR). Soil was completely removed from the root systems of the other three groups of trees and trees

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were stored as bareroot at 2°C in the same cold room with root parts in black plastic bags to prevent water loss. Soil removed from roots was also stored in the same cold room. On April 8, 1999, all plants were moved out from the cold room for treatments. The intact plants in pots were kept without root and soil disturbance, therefore no root damage. One group of plants was transplanted into the same size pots in soil used in the prior year, and about 10% of the root system was removed by volume compared with the intact roots (transplant, TP). One group of plants was root pruned by approximately 25% in volume and transplanted into the same size pots in soil used in the prior year (root prune, RP). The last group was transplanted into the same size pots in soil used in the prior year as a control (CK). Before transplanting, five trees from each of the four groups were sampled and baseline measurement of biomass and N content of roots and shoots were determined. After transplanting all plants were placed outside on a sawdust bed. Five trees from each group received 1 g of  $^{15}\text{NH}_4^{15}\text{NO}_3$  (0.05%  $^{15}\text{N}$  atom depleted, ISOTEC, Inc. Miamisburg, OH, USA) in 250 ml water on April 20, May 19 and June 23 (12, 41 and 76 d after removal from cold storage). Control (CK) trees received the same amount of water without any N. Trees were harvested 10 d after each N application. Only a couple of buds on the top of each tree were breaking at the first harvest (April 30) and there was no new shoot growth. Therefore, the plants were separated into stems (with the breaking buds), shank (rootstock tissue between roots and the graft union) and roots. At other two harvests (May 29 and July 3), plants were separated into new growth (including new stem and leaves), stems (previous year scion tissue between the graft union and new growth), shank (rootstock tissue between roots and the graft union) and roots. During the harvest, soil was carefully washed out from pots to recover the root system as completely as possible. After the harvest, all tissues were washed in DD water and freeze dried. The dry weight was recorded for each tissue with an analytical balance. Samples were ground with a Wiley mill (20 mesh) and reground with a cyclone mill (60 mesh) for determination of total N and  $^{15}\text{N}$  content in each tissue type.

Total N concentration was determined through Kjeldahl analysis (Schuman *et al.*, 1973) by the Central Analysis Laboratory of Oregon State University. The concentration of  $^{15}\text{N}$  in samples was determined from the gas evolved from combustion of powdered tissue in an elemental analyser coupled with a mass spectrometer by the laboratory of Isotope Services, Inc. (329 Potrillo Dr. Los Alamos, NM, USA). The percentage of N derived from fertilizer (NDFF%) in each tissue was calculated as:

$$\text{NDFF\%} = \frac{(\text{atom\%}^{15}\text{N})_{\text{natural abundance}} - (\text{atom\%}^{15}\text{N})_{\text{tissue}}}{(\text{atom\%}^{15}\text{N})_{\text{natural abundance}} - (\text{atom\%}^{15}\text{N})_{\text{fertilizer}}} \times 100\%$$

Concentration of  $^{15}\text{N}$  was calculated from NDFF% and tissue total N content, and amount of  $^{15}\text{N}$  in each tissue was calculated by multiplying  $^{15}\text{N}$  concentration with the dry weight of the tissue. Total  $^{15}\text{N}$  uptake per plant was calculated by pooling the  $^{15}\text{N}$  content in different tissues. The  $^{15}\text{N}$  absorption rate ( $\text{mg } ^{15}\text{N g}^{-1} \text{ root dry weight d}^{-1}$ ) at each harvest was calculated from total  $^{15}\text{N}$  content per

plant divided by root dry weight (RDW) and time of uptake (10 d). Nitrogen use efficiency was calculated as the percentage of  $^{15}\text{N}$  absorbed by plant to total  $^{15}\text{N}$  applied.

The experiment was a randomized design with 80 trees randomly divided into four groups for treatments (five replicates for each treatment at each harvest date). Data of total tree biomass, root biomass, new shoot growth, total N content,  $^{15}\text{N}$  content and uptake rate, and fertilizer N recovery were subjected to a two-factor (treatment and harvest date) analysis of variance (ANOVA) to determine differences among different treatments over time. The separation of means was determined by Duncan's test at  $P = 0.05$ . All statistical analyses were performed with NCSS'97 Statistical System Software (NCSS Statistical Analysis Software, Kaysville, UT, USA).

## RESULTS

### Plant growth

The extent of root damage influenced total biomass of trees during the first 86 d after removal from cold storage (Figure 1). At repotting (8 April), there were no significant differences in total biomass among treatments although there were different root pruning/damages. At the first harvest (30 April), the intact root treatment (IR) had significantly higher biomass than the transplant treatment (TP), which also had significantly higher biomass than the root pruning treatment (RP) and control (CK) treatments, and there was no significant difference in biomass between RP and CK. At the second harvest (29 May), IR still had highest biomass, but there were no significant differences among TP, RP and CK. By 3 July, however the total biomass of trees from the RP and IR treatments was greater than trees from TP and CK treatments. The extent of root damage altered biomass accumulation in roots during the course of the experiment (Figure 2). Initially (8 April), trees from RP had significantly lower root biomass than trees from IR, but by the end of the experiment (3 July), trees

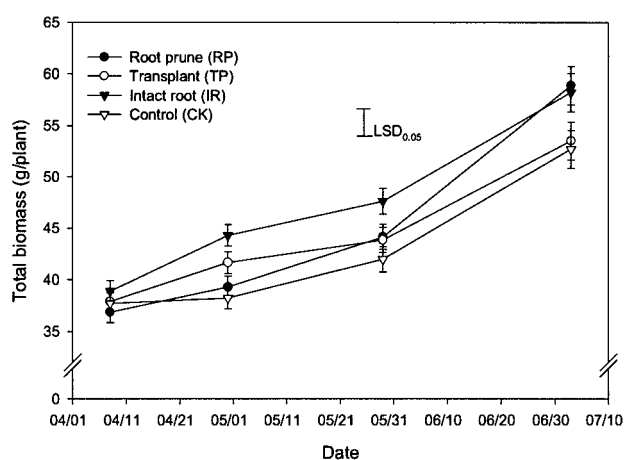


FIG. 1

The influence of root damage at planting on total biomass of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR – closed triangle), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP – open circle); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP – closed circle); Control = stored as bareroot then transplanted (CK – open triangle). Trees removed from storage on 8 April. Bars on data points represent SEs of the mean of five replicates.

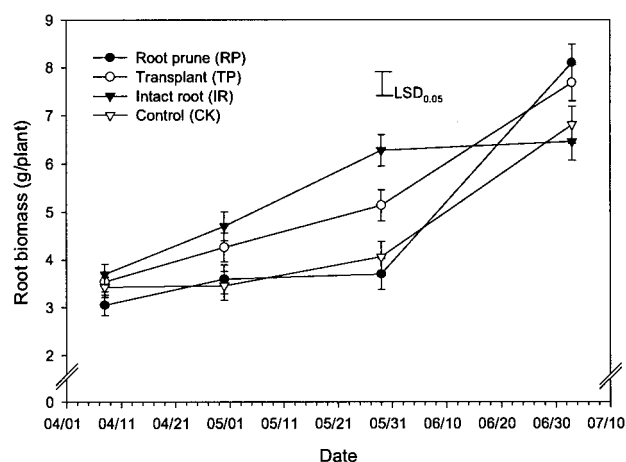


FIG. 2

The influence of root damage at planting on root biomass of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR Treatment – closed triangle), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP Treatment – open circle); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP Treatment – closed circle); Control = stored as bareroot then transplanted (CK – open triangle). Trees removed from storage on 8 April. Bars on data points represent SEs of the mean of five replicates.

from the IR treatment had significantly lower root biomass than trees from RP and TP. Trees from RP had significantly lower root biomass than trees from both IR and TP at first two harvests (30 April and 29 May). On 29 May, only IR treatment had significant higher new shoot biomass than TP treatment, but the trees from the IR, RP and CK treatments all had significantly higher new shoot biomass than TP by the end of the experiment (3 July) (Figure 3).

#### Total N content

Differences in storage conditions between trees in the IR and other treatments had no effect on initial N

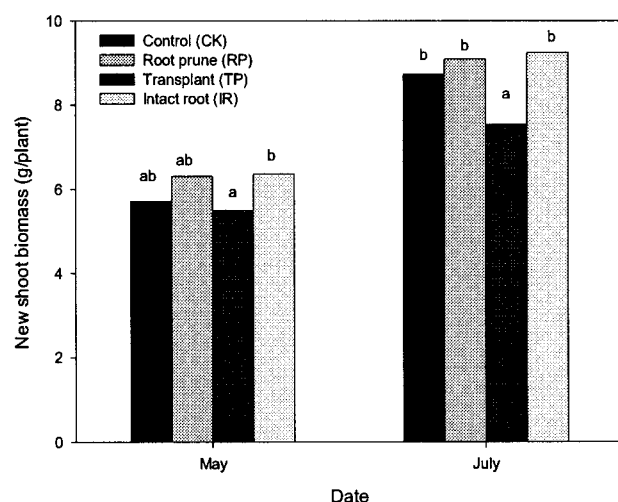


FIG. 3

The influence of root damage at planting on new growth of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP); Control = stored as bareroot then transplanted (CK). Trees removed from storage on 8 April. Letters above columns represent separations of means by Duncan's test at  $P = 0.05$ .

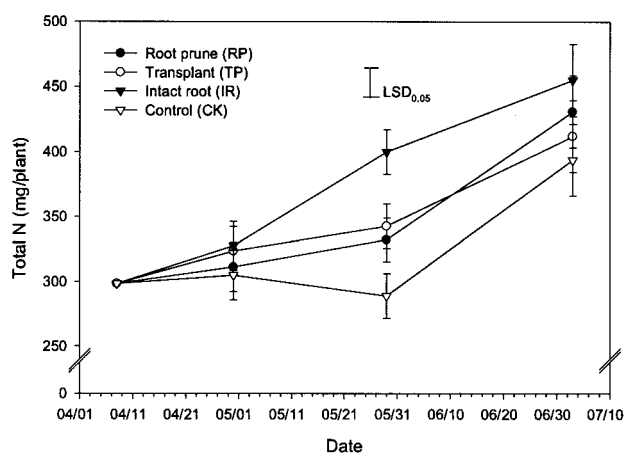


FIG. 4

The influence of root damage at planting on total N content of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR – closed triangle), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP – open circle); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP – closed circle); Control = stored as bareroot then transplanted (CK – open triangle). Trees removed from storage on 8 April. Bars on data points represent SEs of the mean of five replicates.

content per tree. By 51 day (29 May) after repotting, trees from the IR treatment had significant higher N than those from TP and RP, which had significantly higher N than trees from CK (Figure 4). By the end of the experiment, differences in N content between different treatments were not as pronounced.

#### Uptake of $^{15}\text{N}$

Total uptake of  $^{15}\text{N}$  increased for trees from all treatments as the plants grew, but trees with root damage from transplant or root pruning absorbed significantly less  $^{15}\text{N}$  in April and May than trees from the IR treatment (Figure 5). By the end of the experiment, total  $^{15}\text{N}$  uptake of trees from the RP treatment caught up with that of trees from IR, but the

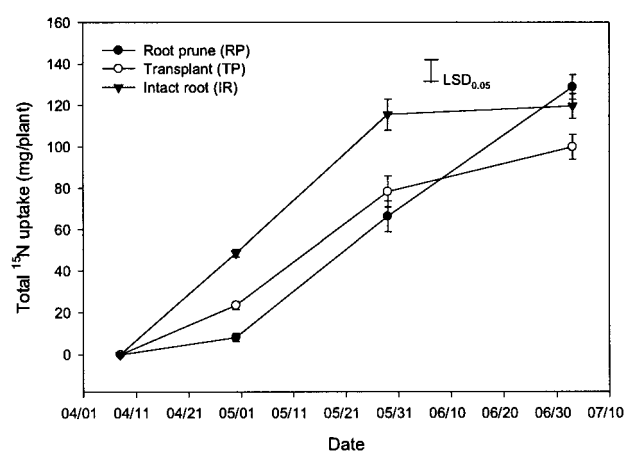


FIG. 5

The influence of root damage at planting on total  $^{15}\text{N}$  uptake (absorption) of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR – closed triangle), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP – open circle); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP – closed circle). Trees removed from storage on 8 April. Bars on data points represent SEs of the mean of five replicates.

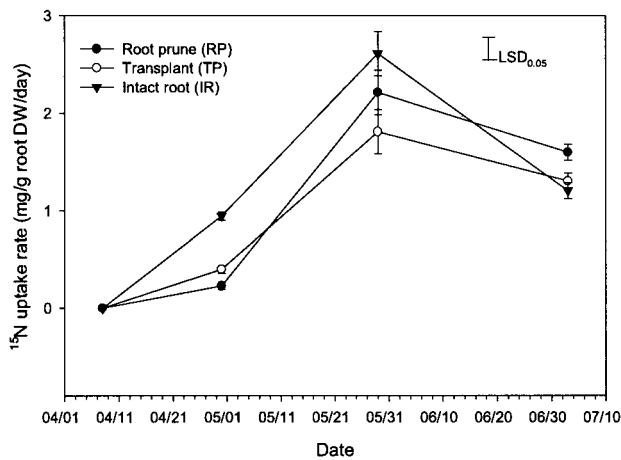


FIG. 6

The influence of root damage at planting on rate of  $^{15}\text{N}$  uptake (absorption) of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR – closed triangle), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP – open circle); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP – closed circle). Trees removed from storage on 8 April. Bars on data points represents SEs of the mean of five replicates.

TP treatment had significantly less  $^{15}\text{N}$  uptake than the IR and RP treatments. The rate of  $^{15}\text{N}$  uptake increased with plant growth until late May, and then decreased with time (Figure 6). The root damage due to root pruning and transplant significantly reduced  $^{15}\text{N}$  uptake rate in April. By late May, there were no significant difference in  $^{15}\text{N}$  uptake rate between IR and RP treatments, but the rate of the TP treatment was still significantly lower than that of the IR treatment. At the end of the experiment, trees from the RP treatment had a significantly higher uptake rate than those from both IR and TP treatments.

#### Distribution of $^{15}\text{N}$

Early in the experiment (30 April), total  $^{15}\text{N}$  uptake was low (Figure 5), and more than 80% of absorbed  $^{15}\text{N}$  was kept in roots (Figure 7). Once new shoot growth started more of the absorbed  $^{15}\text{N}$  was translocated into the new shoot. By late May between 54–62% of the absorbed  $^{15}\text{N}$  was in the new shoot, around 20% in roots, 11–16% in the stem and 6–7% in the shank. The percentage of  $^{15}\text{N}$  in new shoots declined as the growth slowed down in July. In general, root damage did not significantly affect the distribution of absorbed  $^{15}\text{N}$  among different tissues except that RP and IR treatments had low distribution in stem in April and May.

#### Recovery of $^{15}\text{N}$

Both root damage and the growth stage affected the recovery rate of applied  $^{15}\text{N}$  (Figure 8). Twenty-two days after removal from cold storage (30 April), the recovery rate of  $^{15}\text{N}$  by trees in the RP treatment was less than 3% while that of trees in the IR treatment was 14%. There was a negative relationship between the recovery rate and the percentage of root damage on 30 April and 29 May. In early July, trees from the RP treatment had the highest recovery rate of  $^{15}\text{N}$ , but there was no significant difference between recovery rates of trees from the RP and IR treatments.

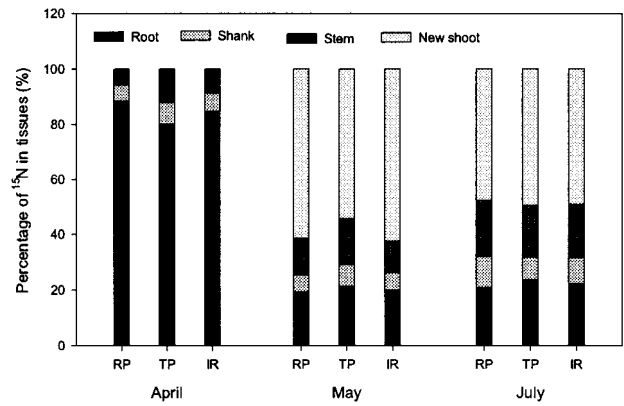


FIG. 7

The influence of root damage at planting on  $^{15}\text{N}$  distribution among different tissues of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP).

## DISCUSSION

The root systems of deciduous nursery stocks are often damaged during the harvesting, storage and transplanting processes, and growers commonly remove the damaged roots of trees before planting. Our results showed that root pruning of young apple trees at planting reduced total biomass during establishment (from April to late May), and thereafter, however, trees that received root pruning grew fast and attained a biomass similar to that of trees with intact roots by early July (Figure 1). Conflicting findings have been reported on the effects of root pruning on plant growth (Geisler and Ferree, 1984a). Root pruning (wrenching) reduced shoot growth and final leaf area in *Prunus avium* and *Castanea sativa* seedlings (Hipps *et al.*, 1996), but increased the length of fine roots (<2 mm diameter) in *Acer pseudoplatanus* (Hipps *et al.*, 1996). Parviainen (1979) found that root-pruned spruce trees started growing in the field later and had a lower height

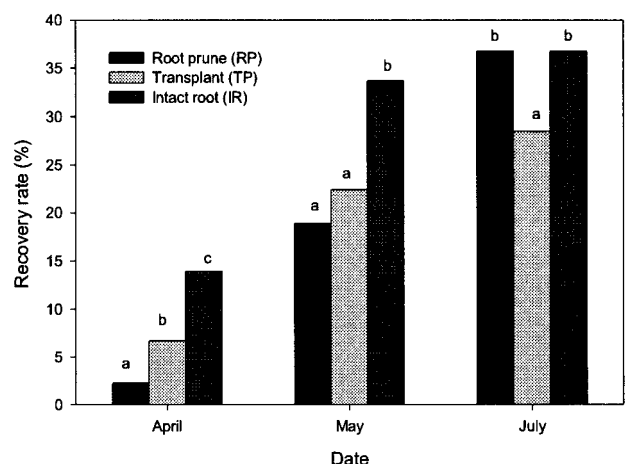


FIG. 8

The influence of root damage at planting on  $^{15}\text{N}$  recovery of Fuji/M.26 apple trees. Intact root = stored with soil and container intact (IR), Transplant = stored as bareroot then transplanted with about 10% of the root system damaged during transplant (TP); Root prune = stored as bareroot then root pruned by 25% prior to transplant (RP). Trees removed from storage on 8 April. Letters above columns represent separations of means by Duncan's test at  $P = 0.05$ .

increment than controls, but Sutton (1967) reported that root pruning at planting time did not affect subsequent growth of spruce trees on fertile soils. Removal of roots before planting reduced 'Cox's Orange Pippin' apple tree's shoot growth, trunk girth increment and final tree weight (Preston, 1972), or resulted in no differences in trunk diameter, average terminal growth and tree height (Rom, 1982). Root pruning during the growing season reduces shoot elongation, shoot diameter, and total dry weight at harvest of one year old greenhouse-grown 'Melrose' on M.7A apple trees (Schupp and Ferree, 1990). Shoot growth rates decrease with increasing the root pruning severity, with the greatest reduction of root extension in the two to three weeks following root pruning (Geisler and Ferree, 1984b). Controversial results among different reports may be due to different climates, plant materials, damage severity, experimental conditions, soil fertility as well as sampling time.

Plants partition biomass to above- and below-ground tissues to maintain relatively constant root:shoot ratio when growing in a given set of environmental conditions. Root pruning or damage reduces this ratio, and plants generally respond by promoting root growth and repressing shoot growth to restore this ratio (Geisler and Ferree, 1984a). Initiation of lateral roots can be stimulated by root pruning at the close cut surface region (Carlson, 1974; Maggs, 1964; Pedersen and Hansen, 1996; Richards and Rowe, 1977a, b; Schupp *et al.*, 1992; Schupp and Ferree, 1987). Our results showed that root growth was first repressed then promoted by root damage from transplant and root pruning (Figure 2). Increased root growth in trees with damaged root systems compensated for root damage in approximately two months after planting.

Root pruning can affect plant nutrient status in several ways. Richards and Rowe (1977a, b) observed that root pruning did not result in nutrient deficiency in peach seedlings, and in contrast, root-pruned plants tended to have higher levels of N, P, K, Ca and Mg than did controls. A single root pruning at either 30 or 55 d after bud break had little effect on foliar nutrient concentrations, but trees root pruned at both 30 and 55 d had a higher foliar levels of N, P, K, Ca, Mg, Fe and B than unpruned trees (Schupp and Ferree, 1990). Schupp *et al.* (1992) reported that root pruning at full bloom had no effect on foliar nutrient content, while Li *et al.* (1996) found root pruning at flowering reduced leaf N content for 28–42 d, but had no effects on leaf P and K in young apple trees. Root-pruning of oak seedlings can lower concentrations of N, P and K in leaves (Rohrig, 1977). Root pruning or damage directly reduces the nutrient absorbing area, and it is reasonable to assume that uptake may decline immediately after pruning. Our results confirm that in young trees total N content is reduced by root pruning during initial plant growth, however differences between damaged and undamaged root systems decreased by 86 d after removal from cold storage (Figure 4).

Pil-shikov (1991) showed that root pruning intensified nutrient uptake in soilless culture experiments with three apple rootstock and field experiments with grafted apple trees. Root pruning of aeroponic tomato plants decreased the total N uptake per plant, but the rate of

uptake per unit root weight was higher in the root-pruning plants (Bar-Tal *et al.*, 1994). Edwards and Barber (1976) also found that total P uptake by intact and trimmed (by 50%) roots was similar, while P uptake per unit root weight was greater in the trimmed roots. N uptake per apple tree was reduced by root restriction, but the flux of N per unit root weight was enhanced (Bar-Yosef *et al.*, 1988). Our results showed that total N uptake and rate of N absorption per unit root dry weight was reduced in April and late May by root pruning, but root pruning increased total <sup>15</sup>N uptake rate in early July (Figures 5 and 6). Plants need time to grow new roots after root pruning and transplanting. Although it has been shown that most parts of the root system are able to absorb nutrients, new roots are the most efficient part (Atkinson, 1980). Therefore, it was not surprising that the uptake rate of N was initially depressed after root pruning. Once trees grow new roots, the abundance of newly developed roots may equalize or even surpass the initial effect of reducing root size (Pedersen and Hansen, 1996). The root restriction in the IR treatment may partially account for the decline of N uptake at the end of the experiment.

Reported N-use efficiencies from soil application of fertilizer vary widely for different tree fruit crops. Hill-Cottingham and Lloyd-Jones (1975) reported that only 16% of <sup>15</sup>N from soil-applied nitrate was recovered when applied in mid-October, while about 40% and 60% of applied <sup>15</sup>N were, respectively, recovered when applied in March and August to young apple trees. Nitrogen-use efficiency declined with increasing soil N application rate for bearing *Citrus* trees and ranged from 14.9% at the rate of 336 g N per year per tree to 42.2% at 140 g N per year per tree (Lea-Cox *et al.*, 2001). In general, N-use efficiency is lower in soil application than foliar application of N, and a typical recovery of soil applied N is between 25–35% (Khemira, 1995). Our results also showed large differences in N-use efficiency at different times of N application and with different amounts of root damage. N-use efficiency in our study ranged from <3% in April to 37% in early July (Figure 7). During initial spring growth, trees with pruned or damaged roots had much lower N-use efficiency than trees with intact root systems. By July, trees with 25% root pruned had N-use efficiency equal to that of trees with intact root systems. In April, we obtained only 13.9% recovery of soil-applied N on plants with intact roots, while Hill-Cottingham and Lloyd-Jones (1975) obtained 40% recovery when application was in March. This difference in recovery may be a result of the time period over which uptake was measured. We measured uptake ten days after N application, while Hill-Cottingham and Lloyd-Jones (1975) measured uptake more than two months after N application.

In summary, root pruning or damage at planting reduced total tree growth and N uptake immediately after planting. It took about two months for trees to regenerate new roots and restore the root system to a similar physical and functional level as in trees with intact root systems. Thereafter tree growth and N uptake was actually promoted by damaged caused by root pruning.

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